U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
OFFICE OF SYSTEMS DEVELOPMENT
TECHNIQUES DEVELOPMENT LABORATORY

TDL OFFICE NOTE 92-13

AN EVALUATION OF SATELLITE SKY COVER ESTIMATES TO COMPLEMENT ASOS OBSERVATIONS

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September 1992

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1. INTRODUCTION

The Automated Surface Observing System (ASOS) that will be gradually implemented starting in September 1992 will provide automated weather observations to replace the manual observations. For many elements, the ASOS observations will be essentially equivalent to the current manual ones; however, for others the ASOS report will have different characteristics.

The cloud observation from ASOS currently will only reliably detect clouds below about 12,000 feet above the surface (NOAA, FAA, and U.S. Navy, 1992). Manual observations, of course, supply information for clouds at all observable heights. While the height of the clouds above 12,000 ft may not be critical to public and aviation interests, the amount of high cloud cover is very important, not only to describe the current weather, but also to help predict elements that are influenced by the clouds, such as the surface temperature and sunshine amount.

One method proposed to provide sky cover information is to combine ASOS observations with estimates of high and middle clouds determined from satellite measurements. The satellite cloud estimates, obtained by a technique developed by the National Environmental Satellite, Data, and Information Service (NESDIS) by the University of Wisconsin, are obtained from the GOES-7 Infra-red (IR) window and the VAS CO_2 absorption band (Menzel and Strabala, 1989). The technique will provide an estimate of cloud top height and coverage for up to three layers of clouds. While capable of estimating low clouds, the satellite estimates are most accurate for clouds tops above 700 mb.

The National Weather Service (NWS) Office of Meteorology recently coordinated a multi-organizational effort to evaluate the satellite cloud product prepared by NESDIS and designed to complement ASOS cloud observations. For its part, the Techniques Development Laboratory (TDL) examined the observations from the standpoint of their importance to public and aviation forecasts, especially for short-range forecasts which are heavily dependent on recent observations.

This office note reports on the TDL evaluation. The ability of satellite observations, in combination with surface reports of clouds below 12,000 ft, to estimate sky cover was examined. Because the cloud top heights reported by the satellite are not routinely available in the surface airways observations (SAOs), and the height of clouds above 12,000 ft is not critical to most public and aviation interests, no attempt to evaluate the cloud height was made. The satellite cloud height information was used only to determine whether the clouds were present above 12,000 ft. The overall quality of the observations from the ASOS/satellite combination was assessed by a comparison with the manual sky cover observations.

2. EVALUATION METHODS

The SAO currently includes manual observations of clouds in multiple layers from the perspective of a ground observer. The cloud base height and the amount of cloud coverage for each layer are reported. The sky cover is cumulative from below, so that the coverage reported for a given layer actually refers to the coverage of all layers below and including that layer. Sky cover, therefore, is equivalent to the amount of coverage of the highest cloud layer. Sky cover is reported in four categories: clear (CLR) for a coverage of less than 1 tenth; scattered (SCT), defined as 1 to 5 tenths coverage; broken (BKN), defined as 6 to 9 tenths sky cover, and overcast (OVC), reported when clouds cover more than 9 tenths of the sky (OFCM, 1988).

The determination of sky cover is complicated by thin clouds, which may range from barely visible to nearly opaque. The total sky cover is defined as the fraction of the sky covered by either thin or opaque clouds. Manual observations distinguish between thin and opaque clouds by layer, with a cloud layer defined as thin when the ratio (summation at and below the level of the layer) of the opaque sky cover to the total sky cover is less than one half. Opaque sky cover only refers to that portion of the sky covered by opaque clouds.

Because ASOS was not deployed at the time of the test, manual observations of sky cover were used to simulate the information that would be available from ASOS. This ASOS simulation used the manual observation of greatest cloud amount for any layer at or below 12,000 ft. The fact that true ASOS observations were not tested is not critical to this analysis, since the objective is to only assess agreement between the satellite and manual observation for clouds above 12,000 ft. <u>The simulated ASOS observations will hereafter be referred to as ASOS observations.</u>

The satellite determines sky cover with an algorithm that processes information from 10 to 25 separate observations surrounding a station. The satellite report provided estimates of up to three layers of cloud with the height of the cloud top, either high (above 400 mb or about 24,000 ft above mean sea level (msl)), middle (between 700 to 400 mb, or around 9,000 to 23,000 ft above msl), and low clouds (below 700 mb or about 9,000 ft above msl).

The effective emissivity of each satellite estimate was also available in the reports that were evaluated. The effective emissivity is a measure of the ratio of the cloud top radiation to the radiation from the earth's surface and depends on both the sky coverage and the transparency of the cloud. The emissivity for an opaque overcast should be 100 percent, and it should be zero for clear skies. An overcast cloud layer with a emissivity significantly less than 100 percent indicates that the layer is thin, since some radiation passes through the clouds. The effective emissivity that distinguishes between thin and opaque clouds for broken skies will, in general, be lower than for overcast conditions, since some IR radiation reaches the satellite from lower levels through the clear air portions of the cloud layer. The effective emissivity was used to provide satellite estimates of thin clouds as detailed later in this paper.

The satellite observations were used, together with ASOS reports, to estimate the sky cover. The combined observations from the satellite and ASOS reports were compared to the complete manual observation. In one test, ASOS was combined with only the satellite high clouds to estimate the sky cover. In this case, the sky cover was obtained from the greater sky coverage of either ASOS or satellite high clouds (defined as ASOS + SATH in the tables that follow). Since the ASOS observational height limit of 12,000 ft occurs within the satellite middle cloud range, another test was made in which the total sky cover was estimated by the greatest coverage from either the ASOS, satellite middle, or satellite high cloud coverage (defined as ASOS + SATMH in the tables that follow). The satellite estimate of low clouds were ignored under the assumption that low clouds will be adequately observed by ASOS alone.

In order to measure the influence of thin clouds, the ASOS/satellite observations were compared to three different sky cover representations that varied according to the treatment of thin clouds reported in the SAOs. For one comparison, the ASOS/satellite observation was compared to the total sky cover from the SAO (referred to as Total in the tables that follow). The reports of opaque sky cover were used for another comparison (referred to as Opaque in the tables that follow). In an attempt to reduce the influence that thin clouds had on the results, a third comparison was made only for cases where the highest cloud layer was not reported to be thin on the SAO. This estimate, labeled Opaque-NTC for "Opaque with no thin clouds" in the text that follows, is identical to the opaque sky cover except that the estimate is only available for evaluation when there are no thin clouds above the highest layer of opaque clouds. This estimate represents a sub-sample in which the influence of thin clouds on the results is greatly diminished. Table 1 displays the cloud amount for the three treatments of thin clouds for several sample SAOs.

Table 1. Sky cover reports for three treatments of thin clouds. The manual cloud observations depict the cloud height in hundreds of feet and the coverage. A "minus" sign after the coverage indicates a thin cloud layer. The values used for the Total, Opaque, and Opaque-NTC sky cover, defined in the text, are displayed both for the complete (Comp.) manual observation and ASOS.

Manual Observation	Total Comp.	Total ASOS	Opaque Comp.	Opaque ASOS	Opaque-NTC Comp.	Opaque-NTC ASOS
50 SCT 150 BKN	BKN	SCT	BKN	SCT	BKN	SCT
50 SCT 150 BKN 250 OVC-	OVC	SCT	BKN	SCT	Eliminated	
50 OVC	OVC	OVC	OVC	OVC	OVC	OVC
250 OVC-	OVC	CLR	CLR	CLR	Eliminated	
250 OVC	OVC	CLR	OVC	CLR	OVC	CLR

All satellite observations reported for the 28-day period between March 16 and April 13, 1992, were evaluated. Satellite observations for 58 locations in the United States shown in Fig. 1 were compared to the SAO reports of sky cover obtained from TDL's hourly data archives. The station list and time period were chosen by the NWS to assure that a uniform sample of data was used by the various agencies involved in the evaluation of the cloud product. Satellite information was provided in a special experimental data set provided

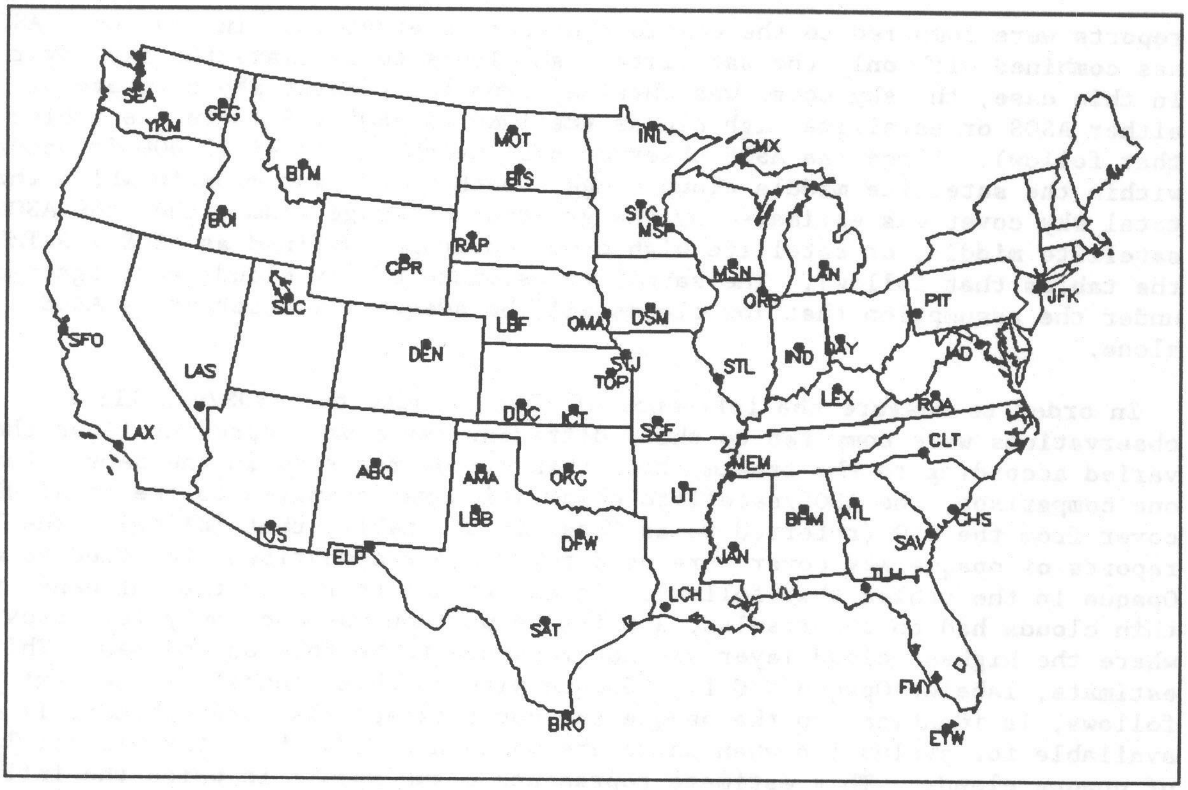

Figure 1. Locations of the stations used for the satellite cloud evaluation. The three letter station identifiers are shown beside each location used.

by NESDIS. During the test, the satellite product was available approximately one third of the time for each station due to the scheduling of the GOES-7 sounder and imager.

Since the quality of cloud reports varies between day and night time, the sample was divided into daytime (1500-2200 UTC) and nighttime (0300-1000 UTC) observations. These periods were chosen to assure daylight/darkness conditions throughout the nation.

3. RESULTS

The sky cover observations were evaluated by the contingency tables with the four possible sky cover categories: CLR, SCT, BKN, and OVC. Comparisons were made for each of the three representations of sky cover: Opaque, Opaque-NTC, and Total. The bias, defined as the ratio of the number of reports in each category from the sky cover estimate being tested to the complete manual observations for each category, is also shown. The contingency table for ASOS reports and the complete manual observation of Opaque-NTC sky cover is shown in Table 2. The corresponding results for the ASOS+SATH sky cover estimates are displayed in Table 3 and the ASOS + SATMH results are shown in Table 4. These results are from daytime observations at all 58 stations.

Without information from clouds above 12,000 ft, ASOS considerably underestimated the sky cover. The bias for overcast conditions of only 0.68 was well below a desirable bias near 1.0. There were too many clear and scattered

Table 2. Contingency table for the ASOS and the complete manual observations (Opaque-NTC) from which the ASOS reports were derived. The number of observations in each category for the 28-day sample between the hours of 1500 and 2200 UTC is shown along with the bias for each category relative to the complete manual observation.

		ASOS				
		CLR	SCT	BKN	OVC	Total
Manual Observation	CLR	1240	0	0	0	1240
	SCT	86	676	0	0	762
	BKN	77	178	560	0	815
	OVC	183	179	236	1251	1849
	Total	1586	1033	796	1251	4666
	Bias	1.28	1.36	0.98	0.68	

reports, with a bias of 1.28 and 1.36 for clear and scattered clouds, respectively.

The ASOS + SATH observations (Table 3) agreed well when there were no clouds, with only 6 reports of broken or overcast skies when the manual observation was clear. However, when there were some clouds, the satellite and manual observation frequently disagreed on the precise amount as indicated by the number of observations that occurred off the diagonal. A sizeable number of the overcast conditions missed by ASOS were also missed by the SATH. Of the 183 cases that ASOS reported CLR when overcast was reported on the manual observation (from Table 2), the satellite missed 48 (Table 3). Since clouds near the 12,000 ft level should occur within the satellite middle cloud layers, this result is not surprising because clouds near 12,000 ft would be missed by the SATH observation alone.

Table 4 reveals that most of the clouds missed by ASOS are detected by the ASOS+SATMH estimate. Of the 183 cases (Table 2) that ASOS reported CLR when the manual observation was OVC, for example, only 3 remained (Table 4). Unfortunately, the frequency that the satellite reported clouds when none were observed on the manual observation was substantially higher than for the ASOS + SATH estimate. The satellite technique also appears to underestimate broken skies, apparently favoring scattered or overcast skies instead, as indicated by the bias of only .58 for broken skies, while bias for SCT and OVC reports was about 1.2.

The distinction between scattered and broken clouds may involve a considerable amount of human subjectivity, since the precise amount of sky cover is difficult to estimate. Even the distinction between clear and scattered or broken and overcast conditions can involve subjective judgments, since clear conditions can be reported with clouds up to about 1 tenth coverage and

Table 3. Same as Table 2 except for the ASOS + SATH cloud cover estimate (see text for definition).

		ASOS + SATH				
		CLR	SCT	BKN	OVC	Total
Manual Observation	CLR	1195	39	2	4	1240
	SCT	73	635	11	43	762
	BKN	31	123	495	166	815
	OVC	48	76	142	1583	1849
	Total	1347	873	650	1796	4666
	Bias	1.09	1.15	0.80	0.97	

Table 4. Same as Table 2 except for the ASOS + SATMH sky cover estimate (see text for definition).

		ASOS + SATMH				
		CLR	SCT	BKN	OVC	Total
Manual Observation	CLR	954	266	5	15	1240
	SCT	49	575	41	97	762
	BKN	8	75	379	353	815
	OVC	3	20	47	1779	1849
	Total	1014	936	472	2244	4666
	Bias	0.82	1.23	0.58	1.21	

overcast conditions can be reported with breaks in the cloud cover. As a result, a single category difference between observations need not always indicate a significant discrepancy. Two category differences, however, almost certainly do. Accordingly, the percent of two category differences was considered here to indicate the amount of discrepancy between the manual and ASOS/satellite observations.

Table 5 displays the fraction of two category discrepancies, relative to the manual observation, for three different methods of estimating the sky cover. The relative frequency that the ASOS/satellite sky cover reported two or more categories fewer clouds than the manual observations is listed under the column labeled "missed", since the satellite missed cloud cover that the observer saw. The percentage of cases that the ASOS/satellite observation overestimated the sky cover by at least two categories, relative to the manual observation, is listed under the column labeled "unreported", since the satellite clouds were unreported in the manual observation. The last column gives the overall percentage of discrepancies, which is the sum of the missed and unreported clouds.

Table 5. Relative frequency of two category discrepancies between the complete manual observation and various ASOS/satellite observation combinations. The sky cover observation listed varies according three estimation algorithms as described in the text.

Sky cover representation/ Observation Combined		Missed	Unreported	
Opaque-NTC				
	ASOS	.09	.00	.09
Day	ASOS + SATH	.03	.01	.04
	ASOS + SATMH	.01	.03	.04
	ASOS	.08	.00	.08
Night	ASOS + SATH	.03	.03	.06
	ASOS + SATMH	.01	.07	.08
Opaque				
	ASOS	.08	.00	.08
Day	ASOS + SATH	.03	.06	.09
	ASOS + SATMH	.01	.13	.14
	ASOS	.06	.00	.06
Night	ASOS + SATH	.02	.06	.08
	ASOS + SATMH	.01	.13	.14
Total				
	ASOS	.17	.00	.17
Day	ASOS + SATH	.08	.01	.09
	ASOS + SATMH	.03	.03	.06
	ASOS	.13	.00	.13
Night	ASOS + SATH	.06	.04	.10
	ASOS + SATMH	.02	.08	.10

A comparison of the two category discrepancies between the daytime manual observations and the ASOS/satellite estimation on a sample without thin clouds (Opaque-NTC) should give an estimate of the satellite error rate since the daytime manual observation are most accurate, and there are no thin clouds to obscure the satellite view or to be misclassified as opaque clouds. From the first three rows on Table 5, the error rate for the satellite and ASOS combination appeared to be about 4 percent of the total cases. For the ASOS + SATH observation, the false alarm rate (found from the rate of unreported satellite clouds) was about 1 percent, but the satellite missed about 3 percent of the manually observed clouds. Almost all of the clouds missed by the ASOS reports were detected by the ASOS + SATMH reports; however, there were more unreported clouds than for the ASOS + SATH observations, so that the overall error rate remained about the same.

Results for sky cover observations which included mixtures of thin and opaque clouds are shown in Table 5 under the groups identified as opaque and total clouds. Daytime observations of opaque clouds indicated that the frequency that the satellite missed an opaque sky cover was not influenced by higher thin clouds since the fraction of missed clouds was the same for both the opaque and opaque-NTC observations (3 and 1 percent for the ASOS + SATH and ASOS + SATMH estimates, respectively). Therefore, high thin clouds did not contribute to the satellite missing opaque clouds that were reported by a manual observer during the day. The presence of thin clouds, however, substantially increased the false alarm rate (represented in the "unreported" column) indicating that the satellite detected the thin clouds. The fraction of unreported clouds for the ASOS + SATMH sky cover observation, for example, increased from 3 percent when compared to the Opaque-NTC sky cover estimates to 13 percent when compared to Opaque sky cover.

For the total sky cover reports, the frequency of unreported clouds was about the same as in the sample uncontaminated by the thin clouds (see daytime observations of unreported clouds between Total and Opaque-NTC sky cover estimates in Table 5), which indicates that the agreement between the satellite and manual observer on the fraction of cloud free sky was not influenced by thin clouds. However when an observer saw clouds (which may have been thin or opaque), the detection rate of the satellite was lower (more clouds were missed) than for the sample with no thin clouds. This indicated that the ASOS/satellite did not detect thin clouds with the same efficiency as for opaque clouds.

The discrepancies between manual and ASOS/satellite observations were generally greater at night than in the day. An examination of the day-night difference in the rate of unreported clouds for opaque and total sky cover in Table 5 strongly suggests that this may have involved the detection of thin clouds. The disagreement between the ASOS/satellite and manual observation was about the same in the day and night when only opaque clouds were considered. However, for total sky cover, the frequency of satellite clouds that were unreported by the manual observations was much higher at night than in the day. Since the only difference between the opaque and total sky cover is the occurrence of thin clouds above the highest opaque layer, this was due to differences in the detection of thin clouds.

The increased frequency of unreported clouds relative to the Opaque-NTC sky cover estimate can most logically be explained by the manual observer failing to detect some high thin clouds at night. A portion of the undetected thin clouds could have been detected by the satellite, and therefore would have resulted in a diurnal difference in rate of unreported satellite clouds.

An attempt was made to determine cloud opacity from the satellite report of the effective emissivity to produce a satellite estimate of opaque sky cover. If the effective emissivity was low (less than 0.66) and yet the satellite sky cover algorithm still reported overcast conditions, the cloud was assumed to be thin. Under the assumption that broken skies may occur with a cloud cover of just over 50 percent, the maximum emissivity required to indicate thin broken clouds was set to half that for overcast conditions, or 0.33. No attempt was made to distinguish thin from opaque scattered clouds. These cutoff values were chosen as a rough estimate; because of the small sample size, no attempt was made to tune the values to produce optimum results.

The results from the satellite estimate of opaque clouds produced by this algorithm are shown in Table 6. The discrepancies between the ASOS/satellite observation and the manual report of Opaque-NTC in the daytime was very low, suggesting an error rate as low as 3 percent as indicated by the combined total of two category errors on the ASOS + SATMH reports. The satellite reports still appear to have detected some thin clouds even after the emissivity adjustment, since there was still a difference in the rate of unreported satellite clouds between daytime samples with and without thin clouds. The frequency of unreported clouds was about five times higher when these satellite observations were compared to Opaque sky cover than they were when compared to the Opaque-NTC sky cover representation. Some opaque clouds were being classified as thin, as well, since the missed clouds were always about 1 percentage point higher than the corresponding observations in Table 5. Still, the results indicated that the effective emissivity can be used to distinguish between thin and opaque clouds.

The daytime results indicated that the greatest agreement between the ASOS/satellite and the manual observation was obtained by the ASOS + SATMH observation used together with the satellite emissivity to determine thin clouds when compared to the Opaque-NTC sky cover. The emissivity adjusted satellite sky cover estimate still occasionally misidentified thin as opaque clouds (as indicated by the higher rate of unreported clouds when Opaque-NTC results are compared to Opaque); however, this was not nearly as much of a problem as when the emissivity was not used. The ASOS + SATMH observation without an emissivity adjustment produced the best estimate of the total sky cover.

4. CONCLUSION

The satellite observations of clouds above 12,000 ft were used together with manual observations of clouds below 12,000 ft to produce total sky cover estimates. The accuracy of these sky cover estimates was tested against the manual observations to determine the ability of the satellite to complement the ASOS observations.

The error rate of the combined ASOS/satellite observation was about 4 percent of the total sample, as suggested by comparison with the Opaque-NTC sky cover in the daytime. The ASOS+SATH estimate missed about 3 percent of the clouds and over reported the extent of sky cover about 1 percent of the time (when compared to the daytime Opaque-NTC sky cover estimates). The ASOS + SATMH observation reduced the fraction of missed clouds, but the false alarm

Table 6. Same as Table 5, except with ASOS/satellite sky cover observations that use the effective emissivity to estimate opaque sky cover.

Sky cover representation/ Observation		Missed	Unreported	Combined
Opaque - NTC				
	ASOS	.09	.00	.09
Day	ASOS + SATH	.05	.004	.05
	ASOS + SATMH	.02	.01	.03
	ASOS	.08	.00	.08
Night	ASOS + SATH	.04	.01	.05
	ASOS + SATMH	.03	.03	.06
Opaque				
	ASOS	.08	.00	.08
Day	ASOS + SATH	.04	.02	.06
	ASOS + SATMH	.02	.05	.07
	ASOS	.06	.00	.06
Night	ASOS + SATH	.03	.02	.05
	ASOS + SATMH	.02	.06	.08

rate increased correspondingly, so that the overall error rate was about the same. An examination of the categorical biases suggests that the satellite sky cover estimates produced fewer observations of broken skies than the manual observer with a slight surplus in clear and scattered clouds.

Many discrepancies between the SAO and ASOS/satellite sky cover estimate were attributed to thin clouds. An examination of the performance of the satellite and manual observation revealed that the satellite detected some, but not all thin clouds. The discrepancies increased at night and when high thin clouds were present. Evidence suggests that discrepancies may result not only from satellite error, but also from inaccurate manual observation of thin clouds at night.

An attempt to distinguish thin from opaque clouds by using the satellite emissivity resulted in substantial reduction of the discrepancies between the satellite and manual observation of opaque clouds. These results suggest that the most accurate method to produce estimates of both total and opaque sky cover from the ASOS and satellite observations is to use the ASOS + SATMH observation together with the emissivity to help distinguish between high thin and opaque clouds.

ACKNOWLEDGEMENTS

Many people from several different organizations helped produce, distribute and evaluate the cloud product. While it would be difficult to identify them all, their efforts are certainly appreciated. The satellite cloud technique was developed at the University of Wisconsin by Dr. Paul Menzel with assistance from Tony Schreiner and Kathy Strabala. Steve Ambrose, Dave Mannarano, Jack Pellett, Richard Ferrare, and Fred Zbar are some of the people whom I've worked with during the course of the evaluation. I am also indebted to Paul Dallavalle for his assistance throughout this investigation and especially for his work with the TDL hourly observation archive. Dr. Menzel's suggestion to use the emissivity to distinguish thin from opaque clouds helped to solve many problems associated with the interpretation of the satellite observations. The helpful assistance of Kimberly Baldwin for writing the satellite observation decoder and Cheryl Grove for assistance with the verification is also greatly appreciated. Gregory Glaros helped compose figures and tables.

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